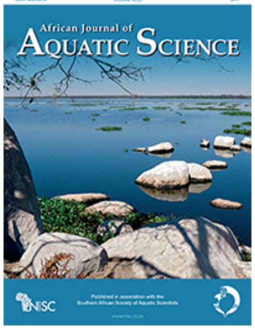

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The ecological integrity of the lower Olifants River, Limpopo province, South Africa: 2009–2015 – Part B: Tributaries of the Olifants River

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Monitoring on the Lowveld reaches of the Olifants River, Limpopo River System, and its Steelpoort, Blyde, Klaserie and Selati tributaries was initiated in 2009. Analysis of the 2009–2015 data from four Olifants River sites showed deterioration in the river's ecological condition between where it enters the Lowveld and where it enters the Kruger National Park, with a slight recovery within the Kruger National Park. Physico-chemical, aquatic macroinvertebrate and fish data collected in 2009–2015 at six sites on the Steelpoort, Blyde, Klaserie and Selati tributaries of the Olifants River corroborated the ecological condition of these tributaries. The Selati was the most polluted and was in a critically modified condition, whereas the Klaserie and Steelpoort were in fair condition and the Blyde was in good condition. The Selati appeared to have a significant negative impact on the water quality, macroinvertebrates and fish of the Olifants River within the Kruger National Park.

Keywords: aquatic macroinvertebrates, freshwater fish, long-term biomonitoring, Lowveld, river health, water quality

Online Supplementary Material: Tables S1 to S3 and Figures S1 and S2 are available online at http://dx.doi.org/10.2989/16085914.2017.1353477

Introduction

Acidification and pollution from mining, industrial, agricultural and domestic activities has systemically impaired the Olifants River, Limpopo River System, making it one of the most polluted river systems in South Africa (Heath et al. 2010; Ashton and Dabrowski 2011). There is consequently justifiable growing concern regarding the long-term impact of water pollution on the aquatic ecosystems of the Olifants River in the Lowveld and Kruger National Park and on the quality of the water that enters Mozambique. However, the upper catchment above Loskop Dam is not the only source of pollution impacting the lower Olifants River. Pollution events from the industries in the Phalaborwa Industrial Complex and poor efficiency of the wastewater treatment facility in Ba-Phalaborwa dramatically impact the Selati tributary of the Olifants River, which joins the Olifants River just upstream of the Kruger National Park (Figure 1).

The impact that pollution from the Selati River has on the Olifants River can be illustrated by the improvement in water quality following a 2004 moratorium on wastewater releases from the Phalaborwa Industrial Complex. The annual median sulphate concentrations in the surface water of the Olifants River at Mamba, approximately 10 km downstream of the confluence with the Selati River, and at Balule a further 50 km downstream (Figure 2), showed dramatic decreases following the 2004 moratorium; declining to levels similar to those at the Phalaborwa Barrage upstream of the confluence with the Selati (Figure 2). However, spills from the Phalaborwa Industrial Complex remain frequent, the most recent being a spill at Bosveld Chemicals in late 2013, which resulted in fish kills in the Kruger National Park (AFP 2014; SANParks 2014).

The Selati River is not the only tributary that could currently be impacting the health of the lower Olifants River. The new dam De Hoop Dam, recently completed on the Steelpoort River (Anonymous 2011), has experienced increasing mining activity in this catchment since 2004. Intensive agriculture dominates the lower reaches of the Blyde River and rapid expansion of rural settlements and crop fields has occurred in the upper reaches of the Klaserie River.

The South African Environmental Observation Network (SAEON) determined that more frequent sampling, and additional sampling sites to supplement those monitored by the existing state-run monitoring programmes, were required to detect major pollution events and to determine long-term trends in the ecological condition of the Lowveld reaches of the Olifants River. Therefore, in 2009 a long-term research project was initiated within the Lowveld reaches of the Olifants River at four sites on the river main stem and six on the largest tributaries in the region: the Steelpoort, Blyde (two sites), Klaserie and the Selati (two sites) rivers. Analysis of the data collected at four sites on the Olifants River between 2009 and 2015 showed deterioration in the ecological condition of the river between Manoutsa, where the river enters the Lowveld and Mamba, just downstream of where it enters the Kruger National

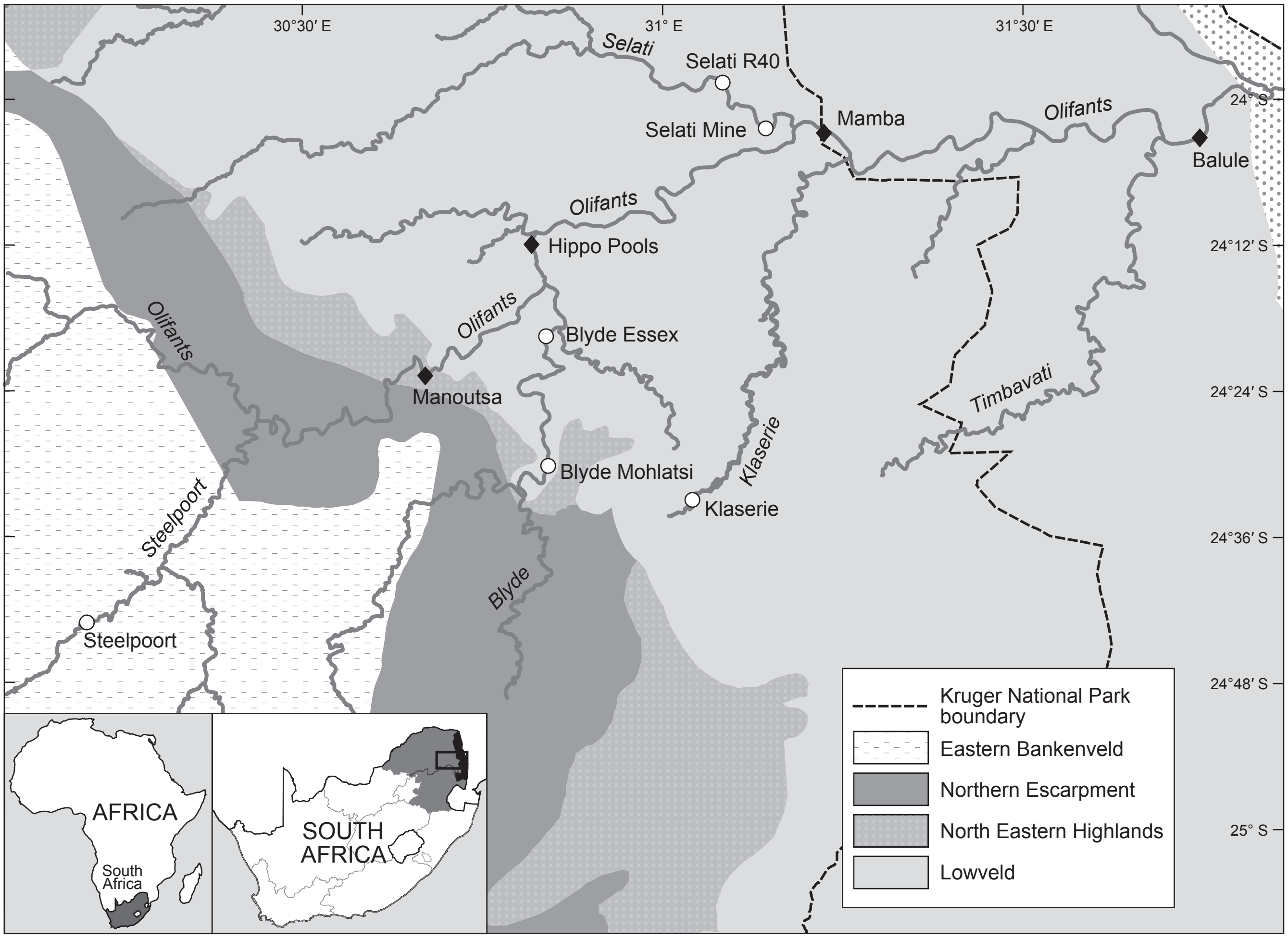

Figure 1: Locations of SAEON sampling sites and of aquatic ecoregions, *sensu* Kleynhans et al. (2005), in the lower Olifants River system. Black diamonds denote locations of the main-stem sites, as described in Marr et al. (2017) white circles the locations of the tributary sites this study

Park, with a slight recovery at Balule further downstream within the Kruger National Park (Marr et al. 2017). This paper assesses the data collected from the Steelpoort, Blyde, Klaserie and Selati tributaries of lower Olifants River from 2009 to 2015 to determine which of the tributaries were driving the trends observed for the main stem of the lower Olifants River.

Material and methods

Sampling localities

Samples were collected at six sites on four tributaries of the Olifants River (Figure 1): Steelpoort River (S 24° 43′ 04″, E 30° 12′ 03″), Mohlatsi (S 24° 30′ 13″, E 30° 50′ 03″) and Essex (S 24° 19′ 32″, E 30° 49′ 53″) on the Blyde River, Klaserie River (S 24° 33′ 01″, E 31° 01′ 55″) and at the R40 (Selati R40) and Lepelle Bridges (Selati Mine) on the Selati River (S 23° 58′ 38″, E 31° 04′ 26″ and S 24° 02′ 17″, E 31° 08′ 00″, respectively).

The Steelpoort River site in the Eastern Bankenveld aquatic ecoregion, *sensu* Kleynhans et al. (2005), was selected to detect pollution inputs to the Olifants River from mining and other activities in the Steelpoort catchment. The Blyde River sites were selected to provide an indication of water quality deterioration resulting from intensive agriculture west of Hoedspruit. The Selati R40 site was selected to provide an indication of pollution inputs from the Selati River upstream of the Phalaborwa Industrial Complex, specifically of the sewage works of Ba-Phalaborwa town. The Selati Mine site was selected to provide an indication of pollution inputs to the Olifants River from both domestic and industrial pollution from Ba-Phalaborwa. The Klaserie River site was selected to provide an indication of pollutants entering the Olifants River from rural villages and small-scale agriculture in the Klaserie catchment.

Water quality, SASS and fish sampling

Sampling took place from 2009 to 2015. *In situ* water temperature, pH, dissolved oxygen and electrical conductivity were recorded (Eutech Instruments Cyberscan PC 300 (2009–2013) and subsequently YSI Model 554 Datalogger). Macroinvertebrates were collected using SASS version 5 kick-sampling (Dickens and Graham 2002) from stones, vegetation, gravel, sand and mud biotopes, using a 1 mm mesh 300 × 300 mm SASS net. Each biotope was sampled,

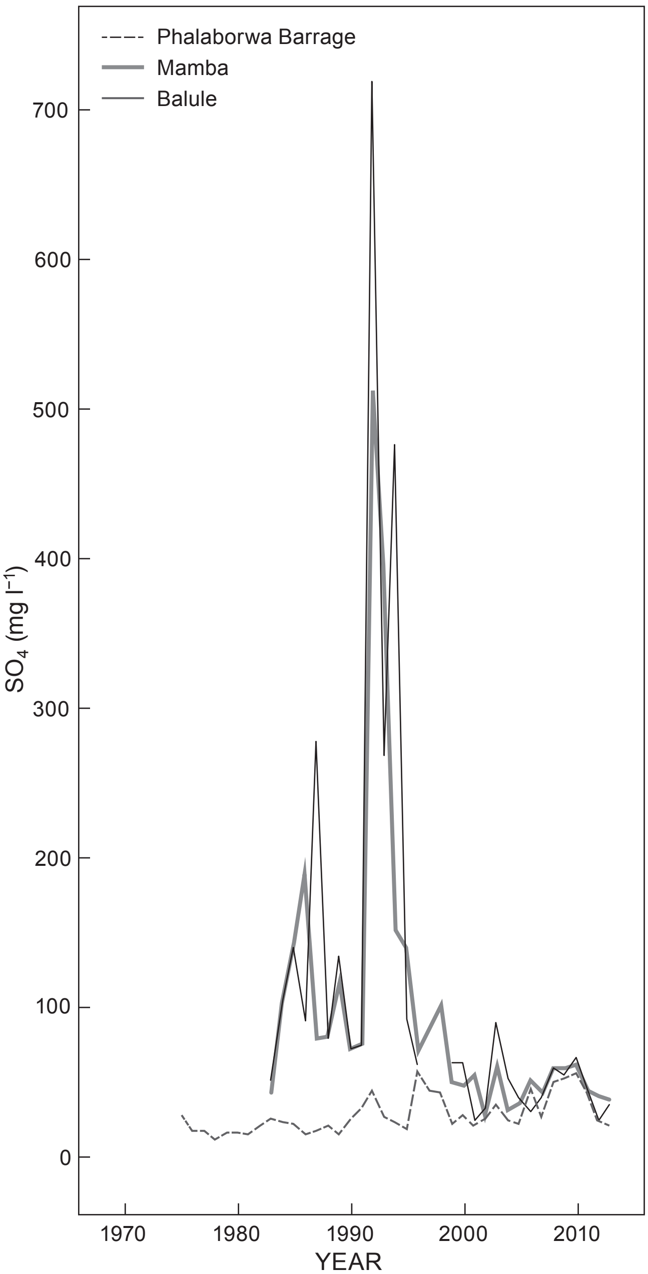

Figure 2: Annual median sulphate concentrations in the surface water of the Olifants River at Phalaborwa Barrage, Mamba and Balule, based on Water Management System data for the Olifants River (Department of Water and Sanitation 2014)

the aquatic macroinvertebrates identified and scored in the field and returned to the river by an accredited SASS practitioner (TM) following Dickens and Graham (2002). Fish were collected using single pass electrofishing utilising a SAMUS Model 760G-backpack electrofisher or, where the conductivity approached 2 000 µS cm^{-1}, a Honda 220 V AC 2 kVa generator. No block nets were used. Fish captured were stored in aerated containers, identified according to Skelton (2001), counted and returned alive to the river. Fish species names were subsequently corrected according to Skelton (2016).

Statistical analyses

Univariate statistical analyses were conducted using R 3.3.1 statistical software (R Development Core Team 2016). Boxplots were prepared to summarise the physico-chemical parameters by site. The Shapiro–Wilk normality test was used to test for normality of the variables, a significant result indicating that the variable was not normally distributed. This was the case for each water physico-chemical parameter, therefore the non-parametric Kruskal–Wallis test was used to evaluate whether the physico-chemical parameters varied between sites. Results were considered statistically significance at $p \leq 0.05$. Dunn tests were used to determine which pairwise interactions contributed to significant Kruskal–Wallis results.

Site SASS scores (the sum of the scores for each taxon recorded) and average score per taxon (ASPT) were calculated for each site visit. The ASPT was plotted against the SASS score and compared to biological bands of the ecological integrity using the composite values for the Eastern Bankenveld and Lowveld aquatic ecoregions from Dallas (2007) – REFERENCE, GOOD, FAIR, POOR and SERIOUSLY OR CRITICALLY MODIFIED. The biological bands were used to provide a means to compare the ecological integrity of the respective tributaries. The uncertainties in the data used to determine these biological bands, especially for the Lowveld aquatic ecoregion, are acknowledged. However, in spite of these uncertainties, the biological bands provide a consistent basis for the comparison of the ecological integrity of the rivers in this study. Boxplots were prepared to summarise the monthly variations in the ASPT in the tributaries of the Olifants River. The temporal variation in the ASPT was summarised in time series plots and a linear regression preformed using only the 'winter' months data (May to August) to evaluate whether any trends in the ASPT could be detected.

Presence-absence data for the aquatic macroinvertebrate taxa was used to evaluate variation in aquatic macroinvertebrate communities. A resemblance matrix was constructed using the Sørensen index (Sørensen 1948), Bray–Curtis similarity equivalent for presence-absence data (Koleff et al. 2003), and a non-metric multidimensional scaling (NMDS) ordination plot (Clarke and Warwick 2001) was prepared to visualise the data using PRIMER E6 statistical software (Clarke and Gorley 2006). PERMDISP and PERMANOVA routines in the PERMANOVA+ extension to PRIMER E6 (Anderson et al. 2008) were used to determine whether the multivariate dispersion about the group centroid differed significantly between the sites and whether the position of the site centroids in multivariate space and/or the multivariate dispersion about the group centroids differed significantly between the sites (Anderson 2001a, 2001b). A SIMPER analysis (Clarke and Warwick 2001) was performed to determine the taxa contributing most to the differences between the sites using PRIMER E6.

The fish abundance data was summarised for each site and the number of species, number of fish and Margalef's diversity index were calculated (Clarke and Warwick 2001). The fish species recorded at each site were compared to the expected fish communities for each ecoregion from Angliss et al. (2005). To provide a metric for the fish communities, the intolerance index of Kleynhans (2005) was used to calculate an average intolerance for each site on a scale of 1 to 5, with the higher number indicating the least tolerant species. A resemblance matrix was constructed using Bray–Curtis similarity of log(x + 1) transformed annual abundance data and an NMDS ordination plot was prepared. In addition, PERMDISP and PERMANOVA analyses were performed to determine whether there were differences in the position of the centroids for each site and a SIMPER analysis was conducted to determine the taxa contributing to similarity within, and dissimilarities between, sites.

Results

Physico-chemical parameters

The pH was significantly different between sites (Kruskal–Wallis $p < 0.001$). The *post hoc* Dunn test revealed that most pairwise pH comparisons were significant, except for the Steelpoort–Selati Mine, Klaserie–Blyde Essex, Selati R40–Selati Mine and Blyde Mohlatsi–Blyde Essex site pairs (Figure 3). The pH range exceeded the target water quality requirement (TWQR) of varying less than 0.5 pH units from background concentrations (DWAF 1996) for all sites, but this could be the result of natural variations in the pH. Conductivity was also significantly different between sites (Kruskal–Wallis $p < 0.001$). The *post hoc* Dunn test revealed that all pairwise conductivity comparisons were significant, except those between Selati R40–Selati Mine and Blyde Mohlatsi–Blyde Essex site pairs. The conductivity exceeded TWQR of 15% of normal cycles in unimpacted systems (DWAF 1996) for both Selati sites and the Steelpoort site (Figure 3). Only the Klaserie site met the conductivity (TDS) TWQR criteria. Dissolved oxygen and oxygen saturation were highly variable within sites, although not significantly different between them (Kruskal–Wallis $p = 0.81$ and $p = 0.21$, respectively). The TWQR for oxygen saturation of 80%–120% saturation (DWAF 1996) was met in less than 25% of the visits for all sites. In fact, the sub-lethal level of 60% saturation (DWAF 1996) was not met in approximately 75% of the visits to all sites and the median value for all sites was below the lethal 40% saturation level (DWAF 1996) (Figure 3). Only temperature displayed seasonal patterns at each site (Figure S1, Supplemental Material). Seasonal patterns were also observed for pH at the Blyde Essex and Klaserie sites and for conductivity at Steelpoort and both Selati sites (Figure S1, Supplemental Material). Linear regression of temperature, pH and conductivity over the winter low-flow months did not return significant results for any of the sites and the R^2 values showed that very little of the variation in the parameters could be explained by the regressions (Table S1, Supplementary Material).

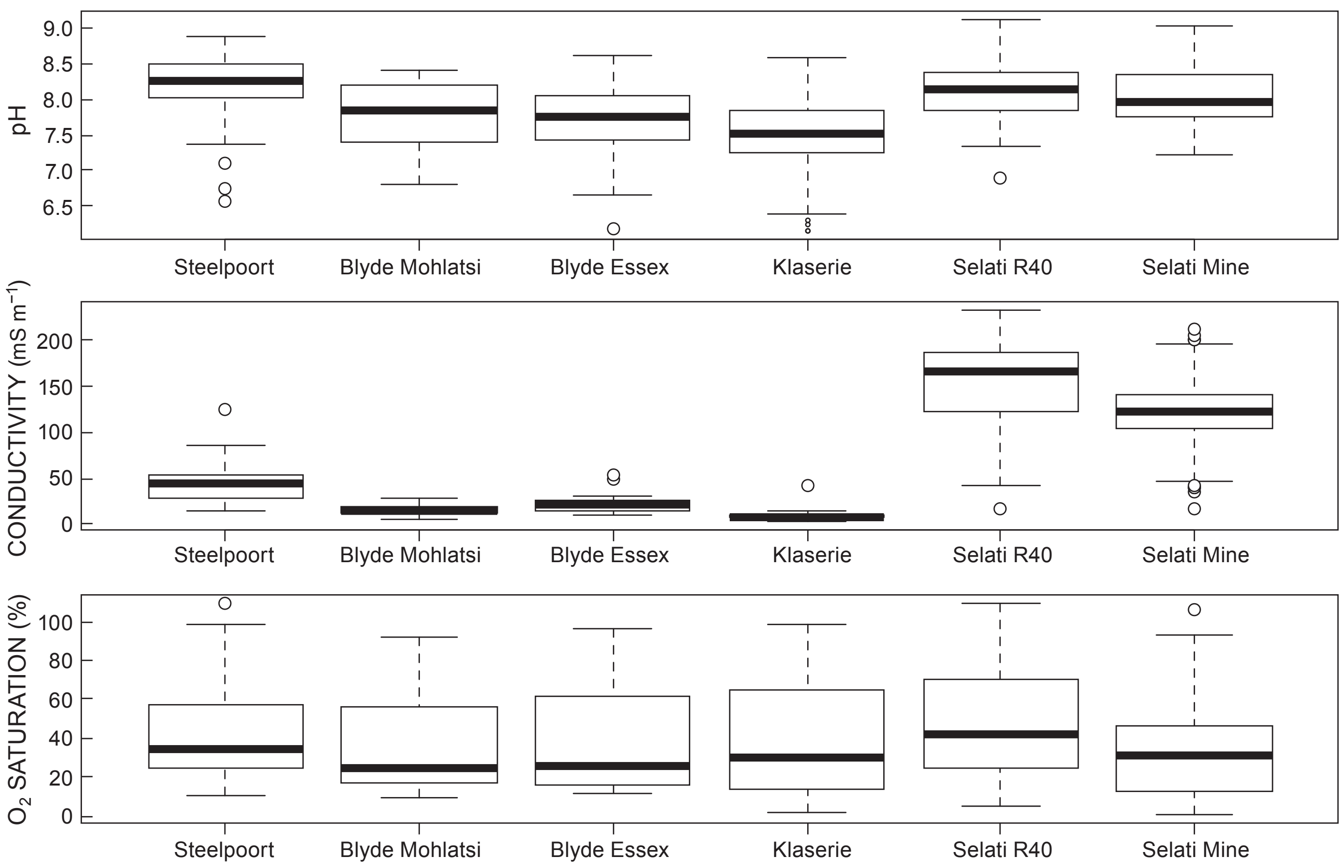

Figure 3: Boxplots summarising variation in selected physico-chemical parameters measured at the study sites between 2009 and 2015

Macroinvertebrates

A list of the macroinvertebrate taxa recorded per site is given in Table S2 (Supplementary Material). A significant difference in ASPT was recorded between the sites (Kruskal–Wallis $p < 0.001$). The *post hoc* Dunn test revealed that there was a significant difference between the Blyde Mohlatsi and Klaserie sites and between both Selati sites and all other sites (Figure 3). No strong correlation between ASPT and the physico-chemical parameters was found for any site (Pearson $R < 0.3$ for all parameters). Time-series data for the site ASPT were plotted for the respective tributaries of the Olifants River and these suggest a declining temporal trend in ASPT for all sites (Figure 4). However, this was not supported statistically ($p > 0.05$), with the exception of Klaserie ($p = 0.007$) and possibly Selati R40 ($p = 0.052$). The trend at Klaserie was the result of low values in 2012 and 2013, which occurred following a major flood in January 2012. At Selati R40, ASPT declined steadily from 2009 to 2012, reaching the values recorded at the Selati Mine site downstream and remained fairly constant at that level thereafter.

A clear separation was evident between the sites in the NMDS plot (Figure 5). The PERMDISP analysis returned a non-significant result ($p = 0.741$) and the PERMANOVA a significant result ($p = 0.001$), indicating a significant difference in the position of the site centroids. A pair-wise PERMANOVA confirmed that the position of each centroid was unique, except those of the two Selati sites. The SIMPER analysis showed that the similarity within the sites was between 40% and 45% (Steelpoort 42%, Blyde 40%, Klaserie 45% and Selati 43%), with the dissimilarity between the sites being >60% (Steelpoort–Blyde 62%, Steelpoort–Klaserie 59%, Steelpoort–Selati 66%, Blyde–Klaserie 60%, Blyde–Selati 70% and Klaserie–Selati 64%). More than 50% of the similarity within the tributaries can be explained by fewer than ten taxa; Steelpoort (Libellulidae 16%, Tabanidae 12%, Gomphidae 12%, Simuliidae 7% and Baetidae >2 sp. 6%), Blyde (Baetidae >2 sp. 7%, Libellulidae 7%, Heptageniidae 7%, Gomphidae 7%, Elmidae 6%, Perliidae 5% Leptaphlebiidae 5%, Tricorythidae 5% and Veliidae 4%), Klaserie (Libellulidae 13%, Gomphidae 12%, Veliidae 8% Baetidae >2 sp. 6%, Elmidae 5% and Coenogrionidae 5%) and Selati (Thiaridae 14%, Libellulidae 12%, Gomphidae 10%, Coenogrionidae 10% and Naucoridae 9%)

Fish

Less than 50% of the species expected at each site were captured (Table 1). This might be an artefact of the sampling technique used (i.e. no use of nets to complement the electrofishing) or of inadequate sampling of the range of habitats at each site. A list of fish species recorded is provided in Table S3 (Supplementary Material).

Margalef's diversity index was highest at the Klaserie and Blyde sites and lowest at the Selati sites. To provide context to the changes in the fish communities recorded, the relative intolerance ratings (Kleynhans 2005) were used to calculate an average index of tolerance for each site on a scale of 1 to 5, with the higher numbers indicating the least tolerant species. The average fish tolerance was highest at the two Blyde sites (3.0) followed closely by the Steelpoort (2.9) and the Klaserie sites (2.8). The average fish intolerance value was lowest at the Selati sites (both

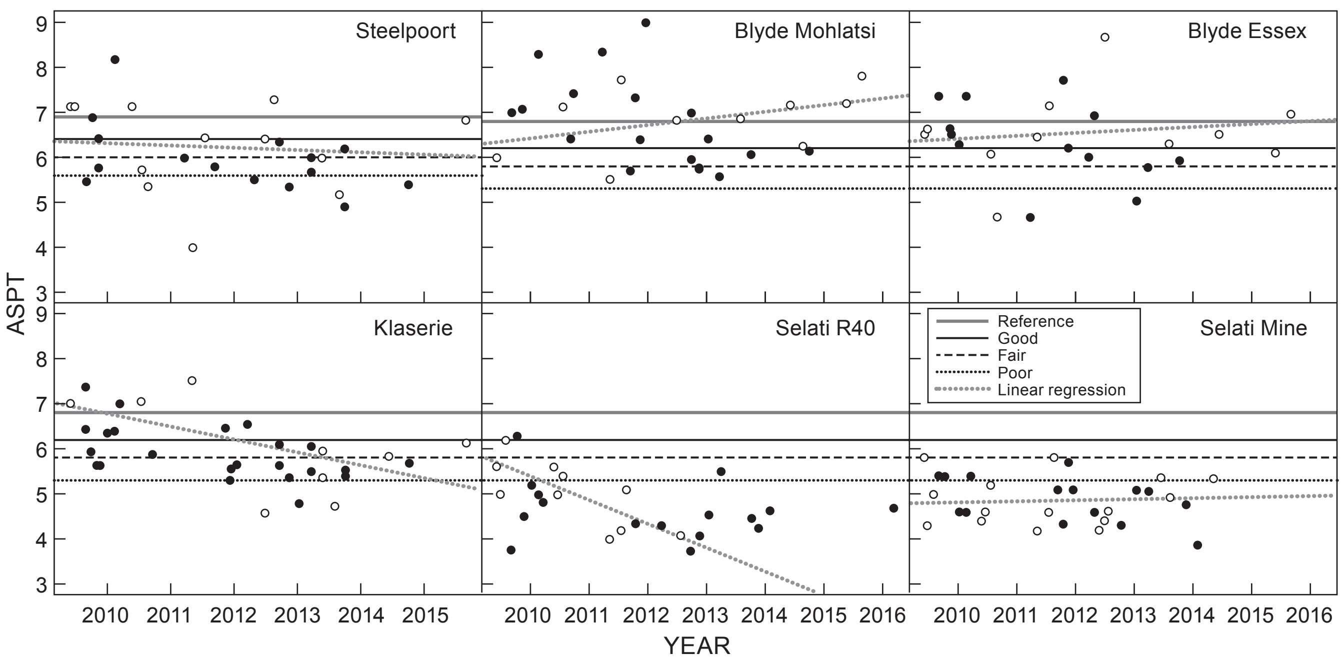

Figure 4: Time series plots summarising average score per taxon (ASPT) calculated from SASS scores at the study sites between 2009 and 2015. Site condition indicated by the various lines: above solid grey line = REFERENCE, above solid black line = GOOD, above dashed line = FAIR, above dotted line = POOR, below dotted line = SERIOUSLY OR CRITICALLY MODIFIED condition. Dotted grey line is a linear regression of ASPT based on the winter months – May to August (open circles)

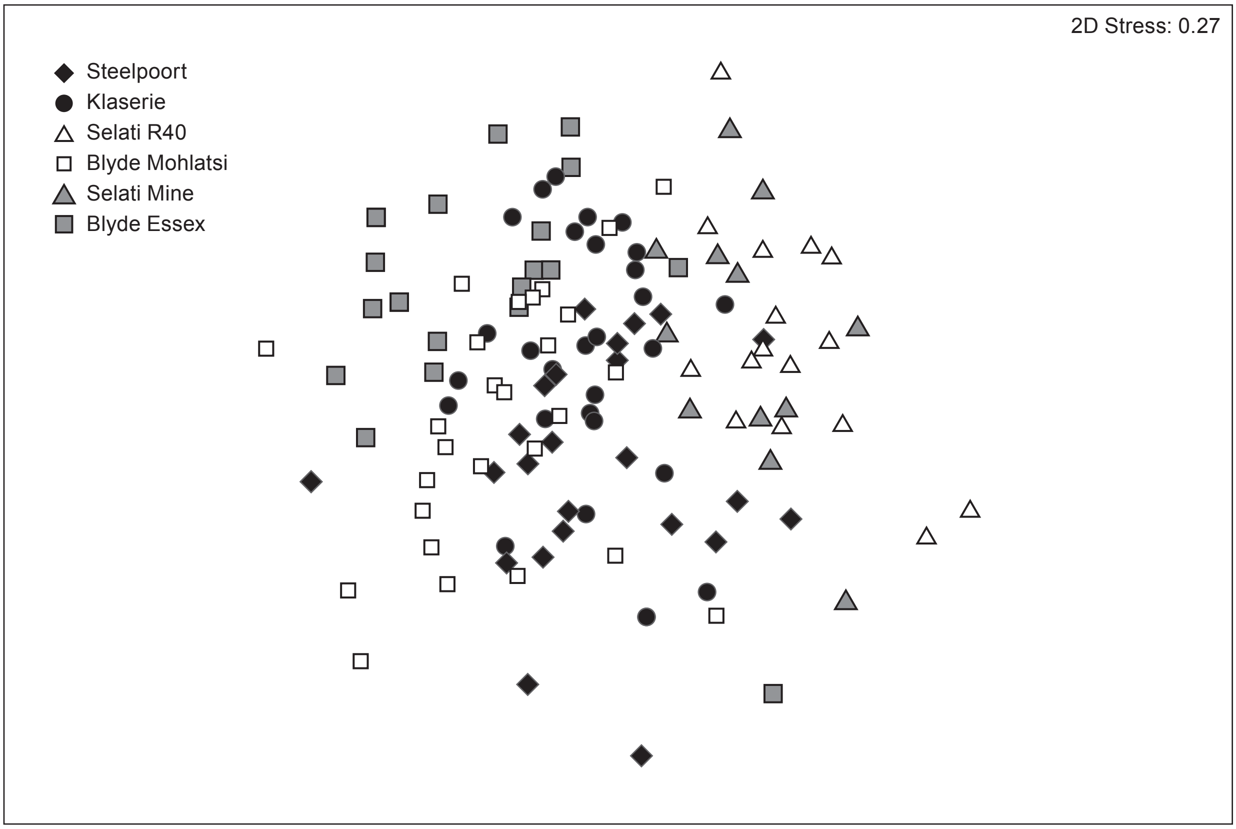

Figure 5: Non-metric multidimensional scaling ordination plots of invertebrate communities in tributaries of the Olifants River between 2009 and 2015. Presence-absence data from SASS was analysed using the Sorensen index to generate the ordination plots. Tributaries depicted by symbols: Steelpoort ♦, Blyde □, Klaserie ● and Selati Δ. Upstream sites (Blyde Mohlatsi and Selati R40) depicted by open symbols, downstream sites (Blyde Essex and Selati Mine) by solid symbols

2.5) indicating that the species present in the Selati are more tolerant of changes in physico-chemical parameters, whereas many species in the Blyde are intolerant.

The NMDS plot of fish communities clearly indicated separation between the sites (Figure 6), which was confirmed by a non-significant result from the PERMDISP analysis and a significant result from the PERMANOVA (p = 0.638 and p = 0.001, respectively). A pair-wise PERMANOVA returned a significant result for all pair-wise interactions, except between the two Selati sites and between the two Blyde sites, thus confirming a significant difference between these tributaries. The SIMPER analysis showed variability of the within-site fish community similarity for the tributaries (Steelpoort 61%, Blyde Mohlatsi 55%, Blyde Essex 62%, Klaserie 53%, Selati R40 69% and Selati Mine 44%). Overall, there was a 44% similarity amongst the fish communities of the Olifants tributary sites. The fish community similarity between the Olifants tributaries was primarily attributable to *Labeobarbus marequensis*, *Chiloglanis paratus*, *Labeo cylindricus*, *Enteromius trimaculatus* and *Labeo molybdinus*, which together contributed to almost 70% of the similarity within the tributaries.

Interestingly, the NMDS plots for aquatic macroinvertebrates and fish showed the same general pattern: the two Selati and the two Blyde sites being separated by the Steelpoort and Klaserie sites. This pattern reflects a gradient from the relatively unimpacted Blyde to the severely impacted Selati, with the Steelpoort and Klaserie sites in between them. This pattern was supported by the median ASPT and fish intolerance data for the respective tributaries. The similarity within the Blyde sites was 59%, with *Chiloglanis paratus*, *Labeobarbus marequensis*, *Opsaridium peringueyi*, *Chiloglanis pretoriae* and *Labeo cylindricus* contributing more than 70% of the similarity, whereas the similarity within the Selati sites was 52%, with *Oreochromis mossambicus, Enteromius trimaculatus*, *Labeobarbus marequensis* and *Clarias gariepinus* contributing almost 70% of the similarity. The dissimilarity between the Blyde and Selati sites was 72%, with *Chiloglanis paratus*, *Oreochromis mossambicus, Opsaridium peringueyi*, *Labeobarbus marequensis*, *Labeo cylindricus, Chiloglanis pretoriae, Coptodon rendalli* and *Micralestes acutidens* contributing more than 70% of the dissimilarity. *Opsaridium peringueyi*, *Chiloglanis pretoriae* and *Micralestes acutidens* were not recorded at the Selati sites, whereas *Coptodon rendalli* was not recorded in the Blyde.

Discussion

The ecological condition of the lower Olifants River degrades from a GOOD condition at Manoutsa, where it

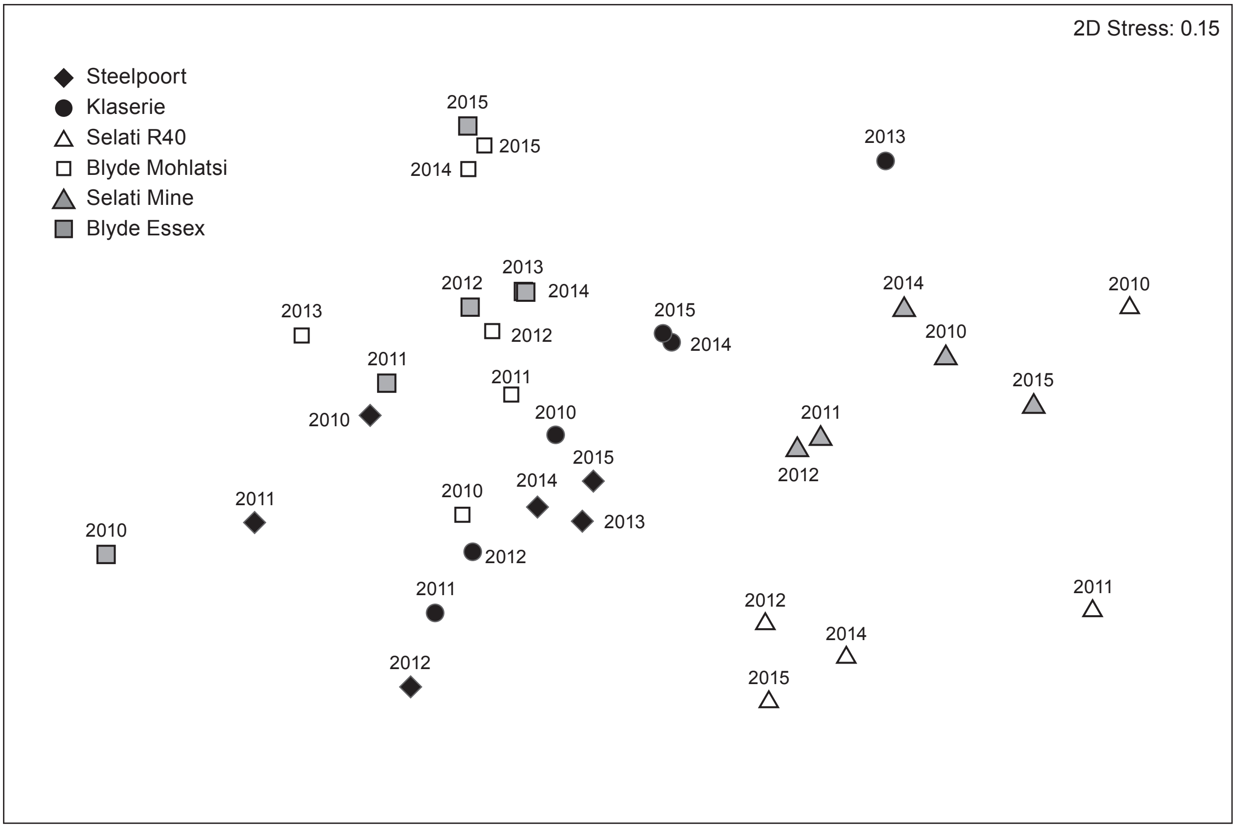

Figure 6: Non-metric multidimensional scaling ordination plot of fish communities in tributaries of the lower Olifants River from 2009 to 2015 based on annual data, log (x + 1) transformed and Bray–Curtis similarity: Steelpoort (♦), Blyde (□), Klaserie (●) and Selati (Δ). Upstream sites (Blyde Mohlatsi and Selati R40) depicted by open symbols, downstream sites (Blyde Essex and Selati Mine) by solid symbols

enters the Lowveld aquatic ecoregion, to a POOR condition at Mamba after its confluence with the Selati and remains POOR through the Kruger National Park to Balule (Marr et al. 2017). The Blyde River tributary, which was found to be in the best ecological condition , enters the Olifants River in a stretch for which Marr et al. (2017) found only a slight deterioration in river health between the Manoutsa and Hippo Pool sites. The Selati River tributary, found here to be in the worst ecological condition, enters the Olifants in a stretch for which Marr et al. (2017) found a substantial deterioration in river health, i.e. between the Hippo Pool and Mamba sites. Finally, the Klaserie River tributary, found here to be in intermediate condition, joins the Olifants between the Mamba and Balule sites, a stretch for which Marr et al. (2017) found a slight improvement in river health. Direct impacts from agriculture and development alongside the Olifants River must also contribute to the trend found along the main-stem. However, these effects are considered to be less important than those of the tributary inputs because nature conservation, i.e. private game reserves and a national park, is the dominant the land use along the Olifants River from Manoutsa to Balule. An area of rural land use immediately downstream of the Manoutsa site and intensive agriculture between Manoutsa and Hippo Pools, could nevertheless have significant, direct effects on the ecological condition of the lower Olifants River. Soil erosion, overgrazing by domestic livestock, rural settlements without sewerage treatment works, excessive abstraction, fertilizer use, pesticides and agricultural return flows could all contribute towards the slight deterioration in the ecological condition of the Olifants River between Manoutsa and Hippo Pools.

Table 1: Summary of fish diversity at sampling sites in lower Olifants River tributaries between 2009 and 2015

Site	No. of species	No. of fish sampled	Margalef's diversity index
Steelpoort	13	1 942	1.585
Blyde Mohlatsi	15	3 238	1.732
Blyde Essex	15	2 786	1.765
Klaserie	16	2 869	1.884
Selati R40	12	1 687	1.480
Selati Mine	11	1 429	1.377

The Steelpoort River, although not in the Lowveld aquatic ecoregion or contributing directly to the change in ecological condition of the lower Olifants River, was included in the study to provide long-term monitoring of the mining-related pollution, the burgeoning rural population and the impact of the completion of the De Hoop Dam. The Steelpoort River appears to be in a FAIR condition and, whereas Ashton and

Dabrowski (2011) suggested that mining and/or industrial activities could have started to have an influence on water quality there, the current results indicate that such influence is still low. The pH and conductivity results of the current study appear to be in accordance with those of Ashton and Dabrowski (2011) for the Steelpoort River. However, the impact of the recently opened mining operations, the rapidly expanding human settlements and the operation of the De Hoop Dam are likely to have a greater impact in the future and ongoing monitoring downstream of these points is warranted. During the course of this study, it was observed that partially or untreated sewage has been flowing into the river, very close to the sampling site, since 2011 (SMM and TDM, pers. obs.). This is ostensibly the result of the wastewater treatment facility at Steelpoort not having enough capacity to treat wastewater from the new housing developments. The increasing orthophosphate concentrations reported by Ashton and Dabrowski (2011) was attributed to discharges of urban runoff or domestic sewage effluent from the expanding towns in the middle and lower reaches. Two additional study sites are required in the Steelpoort catchment to identify all sources of pollution and to monitor fully and understand the expected changes in the ecological condition of this river in the near future. Ideally, new sites should be located above the De Hoop Dam, below the settlements and close to the confluence with the Olifants River.

The ecological condition of both sites in the Blyde River were GOOD, according to the limited metrics and scoring systems used, which is consistent with pH and conductivity data collected by Ashton and Dabrowski (2011) before the current study. There are no large mining or industrial areas within the Blyde catchment. The extensive area of intensive, irrigated agriculture in the middle reaches of the river are considered to have detrimental impacts on the ecological condition of the river through nutrient enriched return flows (Ashton and Dabrowski 2011). The current study found no evidence to support this assertion for all parameters for the Blyde site upstream and downstream of the agriculture. A more comprehensive study, including analysis of nutrients and pesticides, or surrogates for these (e.g. Chlorophyll *a* or diatoms), is required before concluding that agriculture has no effect on the health of the Blyde River. Nevertheless, the water of the Blyde River is in a better ecological condition than that of the Olifants River at their confluence and thus it is likely that the Blyde River currently has a positive influence on the ecological condition of the lower Olifants River.

The Klaserie River appears to be in FAIR condition, although the site monitored is high in the catchment and does not capture the impact of the agriculture and settlements downstream. The water quality reflects the absence of mining and/or industrial activities in the upper reaches of the Klaserie River. The pH and conductivity results of the current study appear to be in accordance with those of Ashton and Dabrowski (2011). However, as for the Steelpoort River, the gradually increasing orthophosphate concentrations reported by Ashton and Dabrowski (2011) could indicate enrichment by nutrients, probably from agricultural return flows. On-going monitoring is needed to determine the long-term impacts of these inputs. Although such impacts might be responsible for the decrease in ASPT values evident between 2011 and 2013, it is more likely that this was as a result of a severe flood in January 2012, which scoured the entire headwater section of the river and drastically altered habitats downstream, including that of the study site. The steady increase in ASPT values from 2013 to 2015 suggests that the macroinvertebrate communities of this river might be recovering following the flood. The recent discovery by the monitoring team of an alien invasive gastropod *Tarebia granifera* (family: Thiaridae), not previously reported in the Klaserie River, is a reason for great concern. The Thiaridae are known to dominate macroinvertebrate communities where they occur (Wolmarans and de Kock 2006; Wolmarans et al. 2014), but its impact on macroinvertebrate assemblages has not yet been sufficiently studied in South Africa. At least one additional monitoring site, closer to the confluence with the Olifants River, is required to evaluate fully the impacts of all land-uses, as well as the invasive gastropod in the Klaserie catchment.

Of the tributaries evaluated in the current study, the Selati River clearly has the largest detrimental impact on the lower Olifants River. Mining and/or industrial activities and excessive water abstraction have had a strong detrimental effect on the water quality of the lower Selati River, but Ashton and Dabrowski (2011) showed that this effect appears to have decreased and stabilized since the 2004 moratorium on discharges from the Phalaborwa Industrial Complex. The pH results of the current study appear to be in accordance with those reported by Ashton and Dabrowski (2011), whereas the conductivity is considerably lower. The obvious explanation for this is that Ashton and Dabrowski (2011) included data from before the 2004 moratorium. The exceptionally high conductivity found at both Selati sites since 2009 indicates a very high solute load, although the source of this was not investigated in the current study. Ashton and Dabrowski (2011) reported predominantly sulphate and chloride anions in the lower Selati River, both of which occur in high concentrations in wastewater produced by the mining and associated industries. Although the water quality in the lower Selati River improved dramatically since the 2004 moratorium (Ashton and Dabrowski 2011), it appears that the river has once again become severely degraded. One of the causes of this could be periodic overflows of wastewater from the Phalaborwa Industrial Complex that still occur regularly. For example, in 2013 a spill of wastewater with a pH less than 2, which continued for up to 7 days resulted in fish kills detected as far downstream as the Mamba site, on the Olifants within the Kruger National Park (AFP 2014; Johanson 2014; Klover 2014; SANParks 2014). However, one of the primary causes of the current high solute load could be the poorly functioning and overloaded wastewater treatment plants at Ba-Phalaborwa town, which discharges into the Selati upstream of both the sites sampled in this study. That similarly high conductivity and low ASPT values were found for both Selati sites support the overloaded wastewater treatment plant hypothesis. The inclusion of a sampling site above the discharges of the wastewater plants would allow this hypothesis to be tested. This was not possible because the river dries up for much of the year upstream of the town. Therefore, for much of the dry season, all the flow of the river within the study reaches derived from the outflows of the wastewater treatment plants plus ground water. Regular monthly biological and chemical oxygen demand and *E. coli* counts for the Selati sites would be very valuable for monitoring the impacts of the wastewater treatment plants, in addition to separating these impacts from those of the industrial complex. Furthermore, the implementation of environmental flows, as stipulated in the National Water Act No 36 of 1998, would curtail the excessive abstraction that occurs in the upper reaches of the river and would result in perennial flows upstream of the town. This would facilitate a monitoring site upstream of the wastewater treatment plants, the dilution of their impacts and as a means to monitor their impacts over the long term.

Conclusions

Despite the limited range of parameters included in the current study, the high frequency of sampling and the number of sampling sites have provided greater insight into trends and drivers of the health of the lower Olifants River tributaries than was previously possible. Continuation and expansion of the study, to include indicators of eutrophication, metal pollution and major anions, particularly sulphate, would allow a better understanding of the influence of the tributaries on the ecological condition of the Olifants River. The monitoring of aquatic macroinvertebrates using the SASS methodology was found to be an efficient way of identifying heavily impacted tributaries, namely the Selati River. The Selati appears to be one of the primary causes of the deterioration in the health of the lower Olifants River in the Lowveld and the Kruger National Park. Focused studies to identify the sources of pollution in the Selati river are required to develop a management plan and mitigation strategy for its rehabilitation.

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